

**APPARATUS AND METHOD FOR GENERATING A PREAMBLE  
SEQUENCE IN AN OFDM COMMUNICATION SYSTEM**

**PRIORITY**

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This application claims priority under 35 U.S.C. § 119 to an application entitled "Apparatus and Method for Generating Preamble Sequence in an OFDM Communication System" filed in the Korean Intellectual Property Office on December 3, 2002 and assigned Serial No. 2002-76419, the contents of which are  
10 incorporated herein by reference.

**BACKGROUND OF THE INVENTION**

1. Field of the Invention

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The present invention relates generally to an orthogonal frequency division multiplexing (OFDM) communication system, and in particular, to an apparatus and method for generating a preamble sequence using a Golay complementary sequence.

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2. Description of the Related Art

In general, a wireless communication system supporting a wireless communication service is comprised of Node Bs and user equipments (UEs). The Node Bs and the UEs support a wireless communication service using transmission frames. Therefore, the Node Bs and the UEs must acquire mutual  
25 synchronization for transmission and reception of transmission frames, and for the synchronization acquisition, a Node B transmits a synchronization signal so that a UE can detect the start of a frame transmitted by the Node B. The UE then detects frame timing of the Node B by receiving the synchronization signal transmitted by the Node B, and demodulates the received frames according to the

detected frame timing. Commonly, a specific preamble sequence previously appointed by the Node B and the UE is used for the synchronization signal.

In addition, a preamble sequence having a low peak-to-average power ratio (PAPR) is used as the preamble sequence in an OFDM communication system, and a preamble created by concatenating a long preamble, which is necessary for performing coarse synchronization, to a short preamble, which is necessary for performing fine frequency synchronization, is used as the preamble transmitted from a Node B to a UE. Further, only the short preamble is used for the preamble transmitted from the UE to the Node B to acquire fine frequency synchronization. The reason the preamble sequence having a low PAPR must be used as a preamble sequence of the OFDM communication system will be described herein below.

Because the OFDM communication system, which is a multicarrier communication system, uses a plurality of carriers, i.e., a plurality of subcarriers, orthogonality between the subcarriers is important. Therefore, phases of the subcarriers are appropriately set so that orthogonality there between is secured, and if the phases are changed during signal transmission/reception through the subcarriers, signals on the subcarriers overlap each other. In this case, the amplitude of the signals that overlap due to the phase change deviates from a linear region of an amplifier included in the OFDM communication system, disabling normal signal transmission/reception. This is the reason why the OFDM communication system uses a preamble sequence having a minimal PAPR.

Further, the OFDM communication system transmits data for several users, or UEs, by time-multiplexing one frame. In the OFDM communication system, a frame preamble indicating a start of a frame is transmitted for a predetermined period beginning at a start point of the frame. Because data may

be irregularly transmitted to the respective UEs within one frame, a burst preamble indicating the start of data is located at a front part of each data block. Therefore, a UE must receive a data frame in order to identify a transmission start point of the data. The UE should be synchronized to a start point of data in order to receive the data, and to this end, the UE must acquire a preamble sequence used in common by all systems for synchronization before receiving signals.

The OFDM communication system is identical to a non-OFDM communication system in a source coding scheme, a channel coding scheme, and a modulation scheme. While a code division multiple access (CDMA) communication system spreads data before transmission, the OFDM communication system performs inverse fast Fourier transform (IFFT) on data and inserts a guard interval in the IFFT-transformed data before transmission. Therefore, compared with the CDMA communication system, the OFDM communication system can transmit a wideband signal with relatively simple hardware.

Further, in the OFDM communication system, if a parallel bit/symbol stream generated by parallel converting a plurality of serial bit/symbol streams is applied as a frequency-domain IFFT input after modulation is performed on data, an IFFT-transformed time-domain signal is output. The time-domain output signal is obtained by multiplexing a wideband signal with several narrowband subcarrier signals, and a plurality of modulation symbols are transmitted for a one-OFDM symbol period through the IFFT process.

However, in the OFDM communication system, if the IFFT-transformed OFDM symbol is transmitted as it is, interference between a previous OFDM symbol and a current OFDM symbol is unavoidable. In order to remove the inter-symbol interference, a guard interval is inserted. The guard interval is used to

insert null data for a predetermined period. However, in a method of transmitting null data for the guard interval, if a receiver incorrectly estimates a start point of an OFDM symbol, interference occurs between subcarriers, causing an increase in an error probability of a received OFDM symbol. Therefore, a “cyclic prefix”  
5 scheme or a “cyclic postfix” scheme has been proposed for the guard interval. In the former scheme, last  $1/n$  bits in a time-domain OFDM symbol are copied and then inserted in an effective OFDM symbol, and in the latter scheme, first  $1/n$  bits in a time-domain OFDM symbol are copied and then inserted in an effective OFDM symbol. A receiver may acquire time/frequency synchronization of a  
10 received OFDM symbol using a characteristic of the guard interval created by copying a part of the one time-domain OFDM symbol, i.e., a beginning part or a last part of one OFDM symbol, and then repeatedly arranging the copied OFDM symbols.

15 In any radio frequency (RF) system, a transmission signal transmitted by a transmitter is distorted while it passes through a radio channel, and thus, a receiver receives a distorted transmission signal. The receiver acquires time/frequency synchronization of the received distorted transmission signal, using a preamble sequence previously set between the transmitter and the  
20 receiver, performs channel estimation, and then demodulates the channel-estimated signal into frequency-domain symbols through fast Fourier transform (FFT). After demodulating the channel-estimated signal into frequency-domain symbols, the receiver performs channel decoding and source decoding corresponding to the channel coding applied in the transmitter on the  
25 demodulated symbols, to thereby decode the demodulated symbols into information data.

The OFDM communication system uses a preamble sequence for all frame timing synchronization, frequency synchronization, and channel estimation.  
30 The OFDM communication system may perform frame timing synchronization,

frequency synchronization, and channel estimation using a guard interval and a pilot subcarrier in addition to the preamble. The preamble sequence is used to transmit known symbols at a beginning part of every frame or data burst, and update estimated time/frequency/channel information at a data transmission part, using information on the guard interval and the pilot subcarrier.

FIG. 1 is a diagram illustrating a structure of a long preamble sequence for a conventional OFDM communication system. It should be noted that a current OFDM communication system uses the same preamble sequence in both a downlink (DL) and an uplink (UP). Referring to FIG. 1, in the long preamble sequence, a length-64 sequence is repeated 4 times and a length-128 sequence is repeated 2 times, and in the light of a characteristic of the OFDM communication system, the above-stated cyclic prefix (CP) is added to a front end of the 4 repeated length-64 sequences and to a front end of the 2 repeated length-128 sequences. In addition, as described above, signals obtained before performing IFFT are frequency-domain signals, while signals obtained after performing IFFT are time-domain signals. The long preamble sequence illustrated in FIG. 1 represents a time-domain long preamble sequence obtained after performing IFFT.

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Frequency-domain long preamble sequences obtained before IFFT are illustrated below.

$$\begin{aligned}
S(-100:100) = \{ & +1+j, 0, 0, 0, +1+j, 0, 0, 0, +1+j, 0, 0, 0, +1-j, 0, 0, 0, -1+j, 0, 0, 0, +1+j, 0, 0, 0, \\
& +1+j, 0, 0, 0, +1+j, 0, 0, 0, +1-j, 0, 0, 0, -1+j, 0, 0, 0, +1+j, 0, 0, 0, +1+j, 0, 0, 0, \\
& +1+j, 0, 0, 0, +1-j, 0, 0, 0, -1+j, 0, 0, 0, +1-j, 0, 0, 0, +1-j, 0, 0, 0, +1-j, 0, 0, 0, \\
& -1-j, 0, 0, 0, +1+j, 0, 0, 0, -1+j, 0, 0, 0, -1+j, 0, 0, 0, -1+j, 0, 0, 0, +1+j, 0, 0, 0, \\
& -1-j, 0, 0, 0, \\
& 0, 0, 0, 0, \\
& 0, 0, 0, 0, \\
& -1-j, 0, 0, 0, +1-j, 0, 0, 0, +1+j, 0, 0, 0, -1-j, 0, 0, 0, -1+j, 0, 0, 0, +1-j, 0, 0, 0, \\
& +1+j, 0, 0, 0, -1+j, 0, 0, 0, +1-j, 0, 0, 0, -1-j, 0, 0, 0, +1+j, 0, 0, 0, -1+j, 0, 0, 0, \\
& -1-j, 0, 0, 0, +1+j, 0, 0, 0, +1-j, 0, 0, 0, -1-j, 0, 0, 0, +1-j, 0, 0, 0, +1+j, 0, 0, 0, \\
& -1-j, 0, 0, 0, -1+j, 0, 0, 0, -1+j, 0, 0, 0, -1-j, 0, 0, 0, +1-j, 0, 0, 0, -1+j, 0, 0, 0, \\
& +1+j\} \cdot \sqrt{2} \cdot \sqrt{2}
\end{aligned}$$

$$\begin{aligned}
P(-100:100) = \{ & -1, 0, +1, 0, +1, 0, +1, 0, +1, 0, -1, 0, -1, 0, -1, 0, +1, 0, -1, 0, +1, 0, \\
& -1, 0, -1, 0, +1, 0, +1, 0, -1, 0, +1, 0, -1, 0, +1, 0, -1, 0, +1, 0, \\
& -1, 0, +1, 0, +1, 0, -1, 0, +1, 0, -1, 0, -1, 0, +1, 0, -1, 0, -1, 0, \\
& -1, 0, +1, 0, +1, 0, -1, 0, +1, 0, +1, 0, +1, 0, -1, 0, +1, 0, +1, 0, \\
& -1, 0, -1, 0, -1, 0, +1, 0, +1, 0, +1, 0, +1, 0, +1, 0, +1, 0, +1, 0, \\
& 0, 0, \\
& -1, 0, -1, 0, +1, 0, -1, 0, -1, 0, +1, 0, +1, 0, +1, 0, -1, 0, +1, 0, \\
& +1, 0, +1, 0, -1, 0, -1, 0, -1, 0, -1, 0, -1, 0, -1, 0, +1, 0, -1, 0, \\
& -1, 0, -1, 0, -1, 0, -1, 0, +1, 0, +1, 0, +1, 0, -1, 0, +1, 0, \\
& -1, 0, +1, 0, +1, 0, -1, 0, +1, 0, +1, 0, +1, 0, -1, 0, -1, 0, -1, 0, \\
& -1, 0, -1, 0, +1, 0, -1, 0, -1, 0, +1, 0, -1, 0, -1, 0, +1, 0, -1\} \\
& \cdot \sqrt{2} \cdot \sqrt{2}
\end{aligned}$$

5            Numerals specified in the frequency-domain long frequency sequences  $S(-100:100)$  and  $P(-100:100)$  represent the subcarriers' positions applied while IFFT is performed, and a detailed description thereof will be made with reference to FIG. 3.  $S(-100:100)$  represents a frequency-domain preamble sequence obtained by repeating a length-64 sequence 4 times, and  $P(-100:100)$  represents a

10 frequency-domain preamble sequence obtained by repeating a length-128 sequence 2 times. In the expression of  $S(-100:100)$  and  $P(-100:100)$ , 'sqrt(2)' means 'root 2', and 'sqrt(2)\*sqrt(2)' means performing double amplification to increase transmission power of  $S(-100:100)$  and  $P(-100:100)$ .

15            FIG. 2 is a diagram illustrating a structure of a short preamble sequence for a conventional OFDM communication system. Referring to FIG. 2, in the short preamble sequence, a length-128 sequence is repeated 2 times, and in the

light of a characteristic of the OFDM communication system, the above-stated cyclic prefix (CP) is added to a front end of the 2 repeated length-128 sequences. In addition, the short preamble sequence illustrated in FIG. 2 represents a time-domain short preamble sequence obtained after performing IFFT, and a  
 5 frequency-domain short preamble sequence equals the above-stated P(-100:100).

The long preamble sequence described above must be generated taking the following conditions into consideration.

10 (1) The long preamble sequence should have a low PAPR.

In order to maximize transmission efficiency of a power amplifier (PA) in a transmitter of an OFDM communication system, a PAPR of an OFDM symbol must be low. That is, because an IFFT-transformed signal is applied to a power amplifier and because of a non-linear characteristic of the power amplifier,  
 15 a low PAPR is required. A PAPR of an OFDM symbol must be low in a ratio of maximum power to average power of a time-domain OFDM symbol corresponding to an IFFT processor's output terminal of the transmitter, and for a low ratio of the maximum power to the average power, uniform distribution must be provided. In other words, a PAPR of an output becomes low if symbols having  
 20 a low cross correlation are combined in an IFFT processor's input terminal of the transmitter, i.e., in a frequency domain.

(2) The long preamble sequence should be suitable for parameter estimation needed for communication initialization.

25 The parameter estimation includes channel estimation, frequency offset estimation, and time offset estimation.

(3) The long preamble sequence should have low complexity and low overhead.

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- (4) Coarse frequency offset estimation should be possible.

A function of the long preamble sequence generated considering the foregoing conditions will now be described herein below.

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- (1) A sequence obtained by repeating a length-64 sequence 4 times is used for time offset estimation and coarse frequency offset estimation.

- (2) A sequence obtained by repeating a length-128 sequence 2 times is  
10 used for fine frequency offset estimation.

As a result, the long preamble sequence has the following uses in the OFDM communication system.

- 15 (1) The long preamble sequence is used as a first preamble sequence of a downlink protocol data unit (PDU).

- (2) The long preamble sequence is used for initial ranging.

- 20 (3) The long preamble sequence is used for bandwidth request ranging.

Further, the short preamble sequence has the following uses in the OFDM communication system.

- 25 (1) The short preamble sequence is used as an uplink data preamble sequence.

- (2) The short preamble sequence is used for periodic ranging.



In the OFDM communication system, because accurate synchronization is acquired by performing initial ranging and periodic ranging, the uplink preamble sequence is mainly used for channel estimation. For channel estimation, PAPR, performance, and complexity should be taken into consideration. In the case of the existing short preamble sequence, a PAPR shows 3.5805[dB], and various channel estimation algorithms such as a minimum mean square error (MMSE) algorithm and a least square (LS) algorithm are used.

FIG. 3 is a diagram illustrating a mapping relation between subcarriers and a preamble sequence during IFFT processing in a conventional OFDM communication system. It is assumed in FIG. 3 that if the number of all of the subcarriers for an OFDM communication system is 256, the 256 subcarriers include  $-128^{\text{th}}$  to  $127^{\text{th}}$  subcarriers, and if the number of subcarriers actually in use is 200, the 200 subcarriers include  $-100^{\text{th}}$ , ...,  $-1^{\text{st}}$ ,  $1^{\text{st}}$ , ...,  $100^{\text{th}}$  subcarriers.

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In FIG. 3, input numerals at an IFFT processor's front end represent frequency components, i.e., unique numbers of subcarriers. The reason for inserting null data, or 0-data, into a  $0^{\text{th}}$  subcarrier is because the  $0^{\text{th}}$  subcarrier, after performing IFFT, represents a reference point of a preamble sequence in a time domain, i.e., represents a DC (Direct Current) component in a time domain. In addition, null data is inserted into 28 subcarriers of the  $-128^{\text{th}}$  to  $-101^{\text{st}}$  subcarriers and 27 subcarriers of the  $101^{\text{st}}$  to  $127^{\text{th}}$  subcarriers, excluding the 200 subcarriers actually in use and the  $0^{\text{th}}$  subcarrier. The reason for inserting null data into 28 subcarriers of the  $-128^{\text{th}}$  to  $-101^{\text{st}}$  subcarriers and 27 subcarriers of the  $101^{\text{st}}$  to  $127^{\text{th}}$  subcarriers is to provide a guard interval in a frequency domain because the 28 subcarriers of the  $-128^{\text{th}}$  to  $-101^{\text{st}}$  subcarriers and the 27 subcarriers of the  $101^{\text{st}}$  to  $127^{\text{th}}$  subcarriers correspond to a high frequency band in the frequency domain.

As a result, if a frequency-domain preamble sequence of  $S(-100:100)$  or  $P(-100:100)$  is applied to an IFFT processor, the IFFT processor maps the frequency-domain preamble sequence of  $S(-100:100)$  or  $P(-100:100)$  to corresponding subcarriers, IFFT-transforms the mapped preamble sequence, and  
 5 outputs a time-domain preamble sequence.

FIG. 4 is a block diagram illustrating a structure of a transmitter in a conventional OFDM communication system. Referring to FIG. 4, if information bits to be transmitted are generated, the information bits are applied to a symbol  
 10 mapper 411. The symbol mapper 411 symbol-maps the input information bits by a preset modulation scheme, and then provides the symbol-mapped bits to a serial-to-parallel (S/P) converter 413. Here, quadrature phase shift keying (QPSK) or 16-ary quadrature amplitude modulation (16QAM) can be used for the modulation scheme. The serial-to-parallel converter 413 parallel-converts  
 15 symbols received from the symbol mapper 411 so that the number of the received symbols is matched to an A-point, which is the number of inputs of an inverse fast Fourier transformer (IFFT processor) 419, and then provides the parallel-converted symbols to a selector 417. A preamble sequence generator 415, under the control of a controller (not shown), generates a corresponding preamble  
 20 sequence and provides the generated preamble sequence to the selector 417. The selector 417 selects a signal output from the serial-to-parallel converter 413 or a signal output from the preamble sequence generator 415 according to scheduling at a corresponding time, and provides the selected signal to the IFFT processor 419.

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The IFFT processor 419 performs A-point IFFT on a signal output from the S/P converter 413 or the preamble sequence generator 415, and provides its output to a parallel-to-serial (P/S) converter 421. In addition to the signal output from the IFFT processor 419, a cyclic prefix with a length  $L$  is applied to the  
 30 parallel-to-serial converter 421. The parallel-to-serial converter 421 serial-

converts the signal output from the IFFT processor 419 and the cyclic prefix, and provides its output to a digital-to-analog (D/A) converter 423. The digital-to-analog converter 423 analog-converts a signal output from the parallel-to-serial converter 421, and provides the analog-converted signal to a radio frequency (RF) processor 425. The RF processor 425 includes a filter, and RF-processes a signal output from the digital-to-analog converter 423 so that it can be transmitted over the air. The RF signal is then transmitted via an antenna.

Now, a description will be made of disadvantages of a preamble sequence generated in a conventional OFDM communication system, and a method for generating the preamble sequence.

(1) In the case of a short preamble sequence used in the existing OFDM communication system, a PAPR is 3.5805[dB], a relatively large value higher than 3[dB].

As described above, a preamble sequence improves the OFDM communication system when a PAPR is minimized. Generally, in data transmission, the value of 3.5805[dB] can be regarded as a relatively small figure that does not affect performance of the OFDM communication system. However, when a preamble sequence used in estimating an initial parameter in the OFDM communication system is taken into consideration, the value of 3.5805[dB] can become a figure that causes performance deterioration of the OFDM communication system. That is, the preamble sequence must be designed so that its PAPR has a value below 3[dB] for initial parameter estimation of the OFDM communication system. However, in the case of a short preamble sequence used in the existing OFDM communication system, a PAPR of 3.5805[dB], a value higher than 3[dB], causes performance deterioration of the OFDM communication system.

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(2) In the existing OFDM communication system, a full search method must be used in order to acquire a preamble sequence having a minimal PAPR. However, the full search method has a long processing time undesirably.

5        Assuming that in the OFDM communication system, a length of a preamble sequence is  $X$  and the number of types of values that elements of the preamble sequence can have is  $Y$ , if the full search is performed in order to acquire a preamble sequence having the minimum PAPR, the search must be performed  $Y^X$  times. For example, if  $Y=2$  and  $X=100$ , the search must be  
10 performed  $2^{100}$  times in order to acquire a preamble sequence having the minimal PAPR. However, the number of  $2^{100}$  operations is a very large number, which creates a huge load on the OFDM communication system.

In order to solve such problems, there are demands for a preamble  
15 sequence having a minimum PAPR, i.e., a PAPR below 3[dB] at the maximum, and a method for generating a preamble sequence having the minimum PAPR with the minimized number of operations within the shortest time.

## SUMMARY OF THE INVENTION

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It is, therefore, an object of the present invention to provide an apparatus and method for generating a preamble sequence in an OFDM communication system.

25        It is another object of the present invention to provide an apparatus and method for generating a preamble sequence having a minimum PAPR in an OFDM communication system.

It is further another object of the present invention to provide an apparatus and method for generating a preamble sequence for minimizing the number of operations in an OFDM communication system.

5           It is still another object of the present invention to provide an apparatus and method for generating a preamble sequence using a Golay complementary sequence in an OFDM communication system.

To achieve the above and other objects, there is provided an apparatus  
10 for generating a preamble sequence in an orthogonal frequency division multiplexing (OFDM) communication system having  $A$  subcarriers in a frequency domain. The apparatus comprises: a preamble sequence generator for generating a length- $M \times N$  preamble sequence, where  $M \times N$  is less than  $A$ , by using a length- $N$  Golay complementary sequence and a length- $M$  Golay  
15 complementary sequence; and an inverse fast Fourier transform (IFFT) processor for assigning elements constituting the preamble sequence to  $M \times N$  subcarriers among the  $A$  subcarriers on a one-to-one mapping basis, assigning null data to the remaining subcarriers excluding the  $M \times N$  subcarriers from the  $A$  subcarriers, and then IFFT-transforming the assigned result into time-domain data.

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To achieve the above and other objects, there is also provided a method for generating a preamble sequence in an orthogonal frequency division multiplexing (OFDM) communication system having  $A$  subcarriers in a frequency domain. The method comprises the steps of: generating a length- $M \times N$   
25 preamble sequence, where  $M \times N$  is less than  $A$ , by using a length- $N$  Golay complementary sequence and a length- $M$  Golay complementary sequence; and assigning elements constituting the preamble sequence to  $M \times N$  subcarriers among the  $A$  subcarriers on a one-to-one mapping basis, assigning null data to

the remaining subcarriers excluding the  $M \times N$  subcarriers from the A subcarriers, and then IFFT-transforming the assigned result into time-domain data.

## BRIEF DESCRIPTION OF THE DRAWINGS

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The above and other objects, features, and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagram illustrating a structure of a long preamble sequence  
10 for a conventional OFDM communication system;

FIG. 2 is a diagram illustrating a structure of a short preamble sequence for a conventional OFDM communication system;

FIG. 3 is a diagram illustrating a mapping relation between subcarriers and a preamble sequence during IFFT processing in a conventional OFDM  
15 communication system;

FIG. 4 is a block diagram illustrating a structure of a transmitter in a conventional OFDM communication system;

FIG. 5 is a block diagram illustrating a structure of a preamble sequence generator according to an embodiment of the present invention;

20 FIG. 6 is a block diagram illustrating a structure of a Golay complementary sequence generation apparatus according to an embodiment of the present invention;

FIG. 7 is a diagram illustrating a rule for mapping a Golay complementary sequence to an IFFT processor's input terminal according to an  
25 embodiment of the present invention;

FIG. 8 is a diagram illustrating a rule for mapping a length-100 Golay complementary sequence to a 256-point IFFT processor's input terminal;

FIG. 9 is a block diagram illustrating a structure of the Golay complementary sequence pair generator of FIG. 6;

FIG. 10 is a block diagram illustrating a structure of a length-10 Golay complementary sequence pair generator;

FIG. 11 is a diagram illustrating a Golay complementary sequence pair combining rule according to an embodiment of the present invention;

5        FIG. 12 is a diagram illustrating a procedure for generating a length-100 Golay complementary sequence pair [S,U] by combining a length-10 Golay complementary sequence pair [O,P] with a length-10 Golay complementary sequence pair [Q,R];

FIG. 13 is a block diagram illustrating a structure of the Golay complementary sequence conjugate pair generator of FIG. 6;

FIG. 14 is a block diagram illustrating a mapping relation between subcarriers and a preamble sequence during IFFT processing in an OFDM communication system according another embodiment of the present invention;

FIG. 15 is a block diagram illustrating a mapping relation between subcarriers and a preamble sequence during IFFT processing in an OFDM communication system having 256 subcarriers; and

FIG. 16 is a flowchart illustrating a preamble sequence mapping procedure according to another embodiment of the present invention.

## 20        **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

Several preferred embodiments of the present invention will now be described in detail with reference to the annexed drawings. In the following description, a detailed description of known functions and configurations  
25 incorporated herein has been omitted for conciseness.

The present invention provides a scheme for generating a preamble sequence having a minimum peak-to-average power ratio (PAPR) in an orthogonal frequency division multiplexing (OFDM) communication system in  
30 which the number of all of subcarriers is A and unique numbers of subcarriers

actually in use are  $-B, -B+1, \dots, -1, 1, \dots, B-1, B$ . In the OFDM communication system, although the actual number of subcarriers is  $A$ , the number of subcarriers into which a preamble sequence is actually inserted becomes  $2B$ , since null data, or 0-data, must be inserted in a  $0^{\text{th}}$  subcarrier indicating a DC component in a time domain and also, the null data must be inserted in subcarriers indicating a guard interval, i.e., corresponding to a high frequency band, in a time domain, as described above in the related art section. In addition, a preamble sequence proposed in the present invention has a PAPR less than 3[dB] at the maximum, and is generated using a Golay complementary sequence.

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The preamble sequence is classified into a long preamble sequence and a short preamble sequence. In the long preamble sequence, a length- $A/4$  sequence is repeated 4 times and a length- $A/2$  sequence is repeated 2 times, and in the light of a characteristic of the OFDM communication system, a cyclic prefix (CP) is added to a front end of the 4 repeated length- $A/4$  sequences and a front end of the 2 repeated length- $A/2$  sequences. Here,  $A$  is the number of all of subcarriers, and represents the number of points, or inputs, of inverse fast Fourier transform (IFFT) which will be described below. For example, if it is assumed that the IFFT processor has 256 points, in the long preamble sequence, a length- $256/4=64$  sequence is repeated 4 times and a length- $256/2=128$  sequence is repeated 2 times. Further, in the short preamble sequence, a length- $A/2$  sequence is repeated 2 times, and in the light of a characteristic of the OFDM communication system, the cyclic prefix (CP) is added to a front end of the 2 repeated length- $A/2$  sequences as described in the related art section.

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A description will now be made of a scheme for generating a preamble sequence according to the present invention.

In an OFDM communication system in which information symbols are transmitted after being IFFT-transformed, if a Golay complementary sequence is

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applied to all input terminals before performing the IFFT, i.e., all subcarriers, then the information symbols after performing the IFFT have a PAPR below 3[dB]. Here, the Golay complementary sequence represents a sequence in which the sum of an aperiodic autocorrelation function for all intervals of a particular  
 5 sequence and an aperiodic autocorrelation function for the same interval of a complementary sequence becomes 0. That is, the Golay complementary sequence can be expressed as follows in Equation 1.

$$\begin{aligned}
 C_A(u) &= \sum_{k=0}^{n-1-u} A_k A_{k+u}^*, \text{ (where } u = 1, 2, \dots, n-2) \\
 C_B(u) &= \sum_{k=0}^{n-1-u} B_k B_{k+u}^*, \text{ (where } u = 1, 2, \dots, n-2) \\
 C_A(u) + C_B(u) &= 0 \quad \dots(1)
 \end{aligned}$$

$C_A(u)$  and  $C_B(u)$  satisfying the above condition make a Golay complementary sequence pair. For example, if the IFFT processor is a 256-point  
 15 IFFT processor, a length-256 Golay complementary sequence is applied to an input terminal of the IFFT processor, and elements constituting the length-256 Golay complementary sequence are applied in association with 256 corresponding points of the IFFT processor. That is, IFFT is performed in such a manner that 256 subcarriers of -128<sup>th</sup> subcarrier to 127<sup>th</sup> subcarrier are mapped to  
 20 256 elements constituting the Golay complementary sequence on a one-to-one basis.

However, in an actual OFDM communication system, null data must be inserted in a subcarrier corresponding to a DC component, i.e., 0<sup>th</sup> subcarrier, and  
 25 subcarriers corresponding to a guard interval component. Therefore, it is impossible to insert respective elements constituting the Golay complementary sequence into all subcarriers of the IFFT processor on a one-to-one mapping basis. That is, because it is impossible to insert the Golay complementary

sequence into the IFFT processor's input terminal on a one-to-one basis, the present invention proposes a rule for inserting the Golay complementary sequence into the IFFT processor's input terminal by mapping, thereby making the best use of a characteristic of the OFDM communication system.

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#### Golay Complementary Sequence Mapping Rule

If respective elements constituting the Golay complementary sequence are inserted into specific subcarriers on an IFFT processor's input terminal to maintain a specific interval between the respective elements of the Golay complementary sequence and then null data is inserted in the remaining subcarriers into which the elements constituting the Golay complementary sequence are not inserted, their outputs after performing IFFT have a PAPR less than 3[dB].

For example, if a specific interval at which Golay complementary sequence elements are inserted into the IFFT processor's input terminal is 1, it means that respective elements constituting the Golay complementary sequence are sequentially inserted, i.e., on a one-to-one basis, into respective subcarriers on the IFFT processor's input terminal. That is, if the specific interval is 1 when a length-256 Golay complementary sequence is inserted into 256-point IFFT, 256 elements of the Golay complementary sequence are inserted into 256 subcarriers on the IFFT processor's input terminal, respectively. However, in the OFDM communication system, because null data should be always inserted into subcarriers corresponding to a DC component and a guard interval component, if a length of the Golay complementary sequence becomes longer than a half of the number of the remaining subcarriers excluding the subcarriers corresponding to the DC component and the guard interval component, it is impossible to continuously insert respective elements constituting the Golay complementary sequence into the IFFT processor's input terminal. However, if the specific interval at which the Golay complementary sequence is inserted into the IFFT

processor's input terminal is 2, there is provided a structure in which respective elements constituting the Golay complementary sequence are sequentially inserted in the subcarriers on the IFFT processor's input terminal every other subcarrier. In addition, null data is inserted into all of the remaining subcarriers into which elements of the Golay complementary sequence are not inserted. Here, if a subcarrier corresponding to a DC component exists in a position other than positions of the subcarriers in which the elements of the Golay complementary sequence are inserted, the Golay complementary sequence can be sequentially arranged on the IFFT processor's input terminal at regular intervals, and as a result, an output after performing the IFFT has a PAPR less than 3[dB].

Describing the existing short preamble sequence, it should be understood that null data is inserted into positions of  $-100^{\text{th}}$  to  $100^{\text{th}}$  subcarriers on a 256-point IFFT processor's input terminal every other subcarrier. However, because null data must be inserted into a subcarrier corresponding to a DC component, i.e., a  $0^{\text{th}}$  subcarrier on the IFFT processor's input terminal, it is impossible that data of +1 or -1, not null data, is inserted in the IFFT processor's input terminal at regular intervals. If data of +1 or -1, not null data, is inserted in the IFFT processor's input terminal every other subcarrier beginning at a  $-99^{\text{th}}$  subcarrier, it is possible that the data is continuously inserted into the IFFT processor's input terminal at regular intervals although null data is inserted into the  $0^{\text{th}}$  subcarrier. That is, respective elements constituting a length-100 Golay complementary sequence consisting of +1 or -1, not null data, are inserted in an input terminal of a 256-point IFFT processor as follows:

$$[-99, -97, \dots, -3, -1, 1, 3, \dots, 97, 99]$$

If null data is inserted in the remaining subcarriers other than the subcarriers identified by  $[-99, -97, \dots, -3, -1, 1, 3, \dots, 97, 99]$ , a PAPR of an output terminal after performing IFFT becomes less than 3[dB].

5 Therefore, the present invention generates a preamble sequence using the Golay Complementary Sequence Mapping Rule described above. In addition, the present invention proposes a method for generating a length-100 Golay complementary sequence capable of supporting the Golay Complementary Sequence Mapping Rule, and this will be described in more detail later on. In the  
10 forgoing description, the Golay Complementary Sequence Mapping Rule has been described for a short preamble sequence with reference to a length-100 Golay complementary sequence. However, because a preamble sequence used in the OFDM communication system varies in length, a generalized Golay Complementary Sequence Mapping Rule will be described with reference to FIG.  
15 7.

FIG. 7 is a diagram illustrating a rule for mapping a Golay complementary sequence to an IFFT processor's input terminal according to an embodiment of the present invention. It is assumed in FIG. 7 that in an OFDM  
20 communication system in which the number of subcarriers on an IFFT processor's input terminal is  $A$ , data is inserted into only the subcarriers identified by  $[-B, -(B-1), \dots, -1, 1, \dots, B-1, B]$ , null data is inserted into the remaining subcarriers, and a specific interval at which a Golay complementary sequence is inserted is  $C$  (where  $C \geq 2$ ).

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In this case,  $B = Ck + D$  (where  $0 \leq D \leq C-1$ ). Thus, respective elements constituting the Golay complementary sequence are inserted in the subcarriers identified by  $[-(B-E), -(B-E-C), \dots, B-F-C, B-F]$  on the IFFT processor's input

terminal, and null data is inserted in the other subcarriers. The parameters D, E, and F will be described herein below.

When the B is a multiple of C, i.e., when  $B = Ck$ , if subcarrier mapping  
 5 of the IFFT processor's input terminal begins at a  $-B^{\text{th}}$  subcarrier, a value of +1 or -1, not null data, must be inserted in a  $0^{\text{th}}$  subcarrier. For  $B = Ck$ , because null data is inserted into the  $0^{\text{th}}$  subcarrier, it is impossible to map the Golay complementary sequence to a preamble sequence. In order to prevent null data from being inserted into the  $0^{\text{th}}$  subcarrier, B for determining a position on the  
 10 IFFT processor's input terminal, at which insertion of respective elements of the Golay complementary sequence is started, is set to  $Ck+D$ . Here, if  $0 \leq D \leq C-1$ , all integers B can be included. In addition, a parameter E is defined in order to prevent a value of +1 or -1, not null data, from being mapped to the  $0^{\text{th}}$  subcarrier. Moreover, a parameter F is defined in order to match a mapping relation for  
 15 inserting the last part of the Golay complementary sequence.

If the Golay complementary sequence is represented by J and a preamble sequence output after performing IFFT on the Golay complementary sequence J is represented by L, then a Golay complementary sequence mapping rule is given  
 20 by Equation as follows:

$$L(i) = \begin{cases} J(n), & i = GPM(n) \\ 0, & i \neq GPM(n) \end{cases} \dots\dots\dots (2)$$

In Equation (2), GPM(n) is an index function, wherein n in GPM(n)  
 25 represents an index of elements constituting a Golay complementary sequence and GPM(n) represents an index of elements constituting a preamble sequence. The GPM(n) is defined in Equation (3) as follows:

$$GPM(n) = -(B - E - nC) \quad \dots \dots \dots (3)$$

In Equation (3),  $-B \leq i \leq B$ , and  $0 \leq n \leq M \times N - 1$ . That is, the parameter  $i$  has a value of  $-B, -(B-1), \dots, -1, 1, \dots, B-1, B$ , and if there is  $n$  satisfying  $i = FPM(n)$ ,  $J(n)$  is inserted in a corresponding subcarrier on an input terminal of an IFFT processor. If there is no  $n$  satisfying  $i = GPM(n)$ , null data is inserted into a corresponding subcarrier on the input terminal of the IFFT processor. A relation between the parameters  $D, E$ , and  $F$  will be described below, considering a situation where data of  $+1$  or  $-1$  should not be inserted into a  $0^{\text{th}}$  subcarrier indicating a DC component while respective elements of the Golay complementary sequence are inserted into subcarriers on an IFFT processor's input terminal at regular intervals as described above.

(1) For  $D=0$ , the parameters are set so that  $E = 1, 2, \dots, C-1$  and  $F=C-E$ .  
 The reason for setting in this manner is because if  $D = E = 0$ , data of  $+1$  or  $-1$ , not null data, is inserted into the  $0^{\text{th}}$  subcarrier on the IFFT processor's input terminal.

(2) For  $D = 1, \dots, C-1$ , the parameters are set so that  $E=0, \dots, C-1 (D+E \neq F)$  and  $F = ((B-F) \bmod C = D + E)$  (for  $0 \leq F \leq C-1$ ).

The reason for setting in this way is to prevent data of  $+1$  or  $-1$ , not null data, from being inserted into the  $0^{\text{th}}$  subcarrier.

A description of FIG. 7 has been made so far for the case where in  $A$ -point IFFT, subcarriers of  $-B, -(B-1), \dots, -1, 1, \dots, B-1, B$  are actually used, a length of a Golay complementary sequence is  $M \times N$ , and the Golay complementary sequence elements are mapped to the IFFT processor's input terminal at intervals of 2. Next, with reference to FIG. 8, a description will be made as to the case where in 256-point IFFT, subcarriers of  $-100, -99, \dots, -1, 1,$

..., 99, 100 are actually used, a length of a Golay complementary sequence is 100, and the Golay complementary sequence elements are mapped to the IFFT processor's input terminal at intervals of 2.

5           FIG. 8 is a diagram illustrating a rule for mapping a length-100 Golay complementary sequence to a 256-point IFFT processor's input terminal. It is assumed in FIG. 8 that in the general Golay Complementary Sequence Mapping Rule described in FIG. 7, a point value A is 256, an integer B for determining a subcarrier position where mapping of the Golay complementary sequence is  
10 actually started is 100, and a specific interval C at which respective elements constituting the Golay complementary sequence are inserted is 2. In this case,  $D=0$  by the general Golay Complementary Sequence Mapping Rule described in FIG. 7, and because  $D=0$ , parameters are set such that  $E=1$  and  $F=C-E=2-1=1$ . Then, the index function  $GPM(n)$  becomes  $GPM(n) = -(99-2n)$  (where  $0 \leq n \leq 99$ ),  
15 so that the length-100 Golay complementary sequence is mapped to elements corresponding to  $[-99, -97, \dots, -1, 1, \dots, 97, 99]$  among the elements constituting a preamble sequence, i.e., subcarriers corresponding to  $[-99, -97, \dots, -1, 1, \dots, 97, 99]$  among 256 subcarriers on an IFFT processor's input terminal. Null data is inserted into the remaining subcarriers to which the Golay complementary  
20 sequence is not mapped.

FIG. 6 is a block diagram illustrating a structure of a Golay complementary sequence generation apparatus according to an embodiment of the present invention. FIG. 6 proposes a method for generating a length- $M \times N$   
25 Golay complementary sequence. Here, M and N are integers satisfying a condition of  $2^\alpha 10^\beta 26^\gamma$ , where  $\alpha, \beta, \gamma \geq 0$ . Referring to FIG. 6, a Golay complementary sequence pair generator 611 is provided with a parameter pNum0 and a parameter seed0 from a controller (not shown), and generates a length-N Golay complementary sequence pair [O,P] according to the provided parameters

pNum0 and seed0. The parameter pNum0 has an integer of 0 to K-1. The parameter K represents the number of length-N primitive Golay complementary sequence pairs. Therefore, the parameter pNum0 is a parameter for selecting a primitive Golay complementary sequence pair, and the parameter seed0 has an integer of 0 to 63 and is a parameter for selecting a conjugate pair of the primitive Golay complementary sequence pair. The reason why the parameter seed0 has an integer of 0 to 63 is because a Golay complementary sequence pair has 64 conjugate pairs. The primitive Golay complementary sequence pair is a Golay complementary sequence pair that cannot be generated through combining of Golay complementary sequence pairs, which are shorter in length than the primitive Golay complementary sequence. A procedure for generating the Golay complementary sequence pair will be described in detail with reference to FIG. 9.

A Golay complementary sequence pair generator 613 is provided with a parameter pNum1 and a parameter seed1, and generates a length-M Golay complementary sequence pair [Q,R] according to the provided parameters pNum1 and seed1. The parameter pNum1 has an integer of 0 to Z-1. The parameter Z represents the number of length-M primitive Golay complementary sequence pairs. Therefore, the parameter pNum1 is a parameter for selecting a conjugate pair of a length-M primitive Golay complementary sequence pair.

A Golay complementary sequence pair combiner 615 combines the length-N Golay complementary sequence pair [O,P] generated from the Golay complementary sequence pair generator 611 with the length-M Golay complementary sequence pair [Q,R] generated from the Golay complementary sequence pair generator 613 according to a parameter 'method' indicating a Golay complementary sequence pair combining rule provided from the controller, and outputs a length-M×N Golay complementary sequence pair [S,U]. The parameter 'method' indicating the Golay complementary sequence pair combining rule has an integer of 0 to 15, and because there are 16 Golay complementary



sequence pair combining rules, one of the 16 rules is set. The Golay complementary sequence pair combining rule will be described in detail herein below with reference to FIG. 11.

5           A Golay complementary sequence conjugate pair generator 617 is provided with a parameter seed2 from the controller, and generates a length- $M \times N$  Golay complementary sequence conjugate pair  $[V, W]$  according to the provided parameter seed2. A procedure for generating the length- $M \times N$  Golay complementary sequence conjugate pair using the length- $M \times N$  Golay  
10 complementary sequence pair will be described in detail herein below with reference to FIG. 13.

Finally, a selector 619 is provided with a select signal from the controller, and selects the Golay complementary sequence pair  $[S, U]$  output from the Golay  
15 complementary sequence pair combiner 615 or the Golay complementary sequence conjugate pair  $[V, W]$  output from the Golay complementary sequence conjugate pair generator 617 according to the provided select signal, and outputs a final Golay complementary sequence J. The select signal has an integer of 0 to 3, and the selector 619 selects V for the select signal=0, W for the select signal=1,  
20 S for the select signal=2, and U for the select signal=3, and outputs the selected signal as the Golay complementary sequence J.

With reference to FIG. 5, a description will now be made of a procedure for actually generating a preamble sequence by mapping the generated Golay  
25 complementary sequence according to the Golay complementary sequence mapping rule.

FIG. 5 is a block diagram illustrating a structure of a preamble sequence generator according to an embodiment of the present invention. Referring to FIG.

5, a preamble sequence generator 500 is comprised of a Golay complementary sequence generator 511 and a Golay complementary sequence/preamble sequence mapper 513. The Golay complementary sequence generator 511 receives parameters pNum0, pNum1, seed0, seed1, seed2, and 'method', and a select signal, and generates a length- $M \times N$  Golay complementary sequence J using the received parameters pNum0, pNum1, seed0, seed1, seed2, and 'method', and the received select signal. An actual Golay complementary sequence generation procedure by the Golay complementary sequence generator 511 has been described with reference to FIG. 6, so a detailed description thereof will be omitted. The length- $M \times N$  Golay complementary sequence  $J(0:M \times N - 1)$  generated from the Golay complementary sequence generator 511 is applied to the Golay complementary sequence/preamble sequence mapper 513, and the Golay complementary sequence/preamble sequence mapper 513 generates a preamble sequence using the length- $M \times N$  Golay complementary sequence  $J(0:M \times N - 1)$  and a parameter 'interval(c)' provided from a controller. The parameter 'interval(c)' represents a specific interval at which a Golay complementary sequence is inserted in an input terminal of an IFFT processor, as described in conjunction with FIGs. 7 and 8, and the Golay complementary sequence/preamble sequence mapper 513 generates a preamble sequence  $Sg(-B:B)$  for the interval(c)=4 and a preamble sequence  $Pg(-B:B)$  for the interval(c)=2. Also, an operation of the Golay complementary sequence/preamble sequence mapper 513 has been described with reference to FIG. 7, so a detailed description thereof will be omitted.

FIG. 9 is a block diagram illustrating a structure of the Golay complementary sequence pair generator 611 illustrated in FIG. 6. Referring to FIG. 9, if it is assumed that the number of length-N primitive Golay complementary sequence pairs 911 is K, a parameter pNum0 has an integer of 0 to K-1. The parameter pNum0 is applied to a selector 913, and the selector 913

selects a length-N primitive Golay complementary sequence pair  $[T_0, T_0^C]$  using the parameter pNum0, and provides the selected length-N primitive Golay complementary sequence pair  $[T_0, T_0^C]$  to a Golay complementary sequence conjugate pair generator 915. The Golay complementary sequence conjugate pair generator 915 generates a Golay complementary sequence conjugate pair  $[O, P]$  using the length-N primitive Golay complementary sequence pair  $[T_0, T_0^C]$  output from the selector 913 and a parameter seed0 provided from the controller.

FIG. 10 is a block diagram illustrating a structure of a length-10 Golay complementary sequence pair generator. Referring to FIG. 10, there are two length-10 primitive Golay complementary sequence pairs 1011, which are given by

$$P_0 = [1, 1, -1, 1, -1, 1, -1, -1, 1, 1]$$

$$P_0^c = [1, 1, -1, 1, 1, 1, 1, 1, -1, -1]$$

$$P_1 = [1, 1, 1, 1, 1, 1, -1, 1, -1, -1]$$

$$P_1^c = [1, 1, -1, -1, 1, 1, 1, -1, 1, -1]$$

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Because there are two length-10 primitive Golay complementary sequence pairs 1011, the parameter pNum0 has a value of 0 or 1, and a selector 1013 selects a length-10 primitive Golay complementary sequence pair using a value of the parameter pNum0 and outputs the selected sequence pair  $[T_0, T_0^C]$ . A Golay complementary sequence conjugate pair generator 1015 generates a Golay complementary sequence conjugate pair  $[O, P]$  using the sequence pair  $[T_0, T_0^C]$  output from the selector 1013 and a parameter seed0 provided from the controller.

FIG. 11 illustrates a Golay complementary sequence pair combining rule according to an embodiment of the present invention. Referring to FIG. 11, the Golay complementary sequence pair combiner 615 illustrated in FIG. 6 combines a length-M×N Golay complementary sequence pair according to a Golay

complementary sequence pair combining rule ‘method’. The Golay complementary sequence pair combining rule ‘method’ is listed below.

### Golay Complementary Sequence Pair Combining Rule

method=0

$$s_i = 0.5 \times [q_k(o_i + p_i) + r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [r_k(o_i + p_i) - q_{M-i+k}(o_i - p_i)]$$

method=1

$$s_i = 0.5 \times [q_{M-i+k}(o_i + p_i) + r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [r_k(o_i + p_i) - q_k(o_i - p_i)]$$

method=2

$$s_i = 0.5 \times [q_k(o_i + p_i) + r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [r_{M-i+k}(o_i + p_i) - q_{M-i+k}(o_i - p_i)]$$

method=3

$$s_i = 0.5 \times [q_{M-i+k}(o_i + p_i) + r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [r_{M-i+k}(o_i + p_i) - q_k(o_i - p_i)]$$

method=4

$$s_i = 0.5 \times [-q_k(o_i + p_i) + r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [r_k(o_i + p_i) + q_{M-i+k}(o_i - p_i)]$$

method=5

$$s_i = 0.5 \times [-q_{M-i+k}(o_i + p_i) + r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [r_k(o_i + p_i) + q_k(o_i - p_i)]$$

method=6

$$s_i = 0.5 \times [-q_k(o_i + p_i) + r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [r_{M-i+k}(o_i + p_i) + q_{M-i+k}(o_i - p_i)]$$

method=7

$$s_i = 0.5 \times [-q_{M-i+k}(o_i + p_i) + r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [r_{M-i+k}(o_i + p_i) + q_k(o_i - p_i)]$$

method=8

$$s_i = 0.5 \times [q_k(o_i + p_i) - r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_k(o_i + p_i) - q_{M-i+k}(o_i - p_i)]$$

method=9

$$s_i = 0.5 \times [q_{M-i+k}(o_i + p_i) - r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_k(o_i + p_i) - q_k(o_i - p_i)]$$

method=10

$$s_i = 0.5 \times [q_k(o_i + p_i) - r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_{M-i+k}(o_i + p_i) - q_{M-i+k}(o_i - p_i)]$$

method=11

$$s_i = 0.5 \times [q_{M-i+k}(o_i + p_i) - r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_{M-i+k}(o_i + p_i) - q_k(o_i - p_i)]$$

method=12

$$s_i = 0.5 \times [-q_k(o_i + p_i) - r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_k(o_i + p_i) + q_{M-i+k}(o_i - p_i)]$$

method=13

$$s_i = 0.5 \times [-q_{M-i+k}(o_i + p_i) - r_{M-i+k}(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_k(o_i + p_i) + q_k(o_i - p_i)]$$

method=14

$$s_i = 0.5 \times [-q_k(o_i + p_i) - r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_{M-i+k}(o_i + p_i) + q_{M-i+k}(o_i - p_i)]$$

method=15

$$s_i = 0.5 \times [-q_{M-i+k}(o_i + p_i) - r_k(o_i - p_i)]$$

$$u_i = 0.5 \times [-r_{M-i+k}(o_i + p_i) + q_k(o_i - p_i)]$$

5

In the Golay Complementary Sequence Pair Combining Rule,  $o_i$  and  $p_i$  represent elements constituting a length-N Golay complementary sequence pair [O,P],  $q_k$  and  $r_k$  represent elements constituting a length-M Golay complementary sequence pair [Q,R], and  $s_i$  and  $u_i$  represent elements constituting a length-M×N Golay complementary sequence pair [S,U]. Here,  $i$ ,  $l$ , and  $k$  satisfy a condition of Equation (4) below.

$$0 \leq i \leq M \times N - 1, \quad l \equiv i(\text{mod } N), \quad k = \left\lfloor \frac{i}{N} \right\rfloor \quad \dots\dots\dots (4)$$

As a result, in the Golay complementary sequence generator illustrated in  
 5 FIG. 6, if the controller assigns a parameter 'method' indicating the Golay  
 complementary sequence pair combining rule in accordance with the Golay  
 Complementary Sequence Pair Combining Rule, the Golay complementary  
 sequence pair combiner 615 generates a length- $M \times N$  Golay complementary  
 sequence pair [S,U] by combining a length- $N$  Golay complementary sequence  
 10 pair [O,P] with a length- $M$  Golay complementary sequence pair [Q,R].

FIG. 12 is a diagram illustrating a procedure for generating a length-100  
 Golay complementary sequence pair [S,U] by combining a length-10 Golay  
 complementary sequence pair [O,P] with a length-10 Golay complementary  
 15 sequence pair [Q,R]. Referring to FIG. 12, the Golay complementary sequence  
 pair combiner 615, as described in conjunction with FIG. 6, is provided with a  
 parameter 'method' indicating the Golay Complementary Sequence Pair  
 Combining Rule from the controller, and generates a combined length-100 Golay  
 complementary sequence pair [S,U] according to the provided parameter  
 20 'method'. The parameter 'method' indicating the Golay Complementary  
 Sequence Pair Combining Rule has 16 values of 0 to 15, and the 16 kinds of  
 length-100 Golay Complementary Sequence Pair Combining Rules are listed  
 below.

#### 25      Length-100 Golay Complementary Sequence Pair Combining Rule

method=0	method=8
$s_i = 0.5 \times [q_k(o_i + p_i) + r_{9-k}(o_i - p_i)]$	$s_i = 0.5 \times [q_k(o_i + p_i) - r_{9-k}(o_i - p_i)]$
$u_i = 0.5 \times [r_k(o_i + p_i) - q_{9-k}(o_i - p_i)]$	$u_i = 0.5 \times [-r_k(o_i + p_i) - q_{9-k}(o_i - p_i)]$
method=1	method=9
$s_i = 0.5 \times [q_{9-k}(o_i + p_i) + r_{9-k}(o_i - p_i)]$	$s_i = 0.5 \times [q_{9-k}(o_i + p_i) - r_{9-k}(o_i - p_i)]$
$u_i = 0.5 \times [r_k(o_i + p_i) - q_k(o_i - p_i)]$	$u_i = 0.5 \times [-r_k(o_i + p_i) - q_k(o_i - p_i)]$
method=2	method=10
$s_i = 0.5 \times [q_k(o_i + p_i) + r_k(o_i - p_i)]$	$s_i = 0.5 \times [q_k(o_i + p_i) - r_k(o_i - p_i)]$
$u_i = 0.5 \times [r_{9-k}(o_i + p_i) - q_{9-k}(o_i - p_i)]$	$u_i = 0.5 \times [-r_{9-k}(o_i + p_i) - q_{9-k}(o_i - p_i)]$
method=3	method=11
$s_i = 0.5 \times [q_{9-k}(o_i + p_i) + r_k(o_i - p_i)]$	$s_i = 0.5 \times [q_{9-k}(o_i + p_i) - r_k(o_i - p_i)]$
$u_i = 0.5 \times [r_{9-k}(o_i + p_i) - q_k(o_i - p_i)]$	$u_i = 0.5 \times [-r_{9-k}(o_i + p_i) - q_k(o_i - p_i)]$
method=4	method=12
$s_i = 0.5 \times [-q_k(o_i + p_i) + r_{9-k}(o_i - p_i)]$	$s_i = 0.5 \times [-q_k(o_i + p_i) - r_{9-k}(o_i - p_i)]$
$u_i = 0.5 \times [r_k(o_i + p_i) + q_{9-k}(o_i - p_i)]$	$u_i = 0.5 \times [-r_k(o_i + p_i) + q_{9-k}(o_i - p_i)]$
method=5	method=13
$s_i = 0.5 \times [-q_{9-k}(o_i + p_i) + r_{9-k}(o_i - p_i)]$	$s_i = 0.5 \times [-q_{9-k}(o_i + p_i) - r_{9-k}(o_i - p_i)]$
$u_i = 0.5 \times [r_k(o_i + p_i) + q_k(o_i - p_i)]$	$u_i = 0.5 \times [-r_k(o_i + p_i) + q_k(o_i - p_i)]$
method=6	method=14
$s_i = 0.5 \times [-q_k(o_i + p_i) + r_k(o_i - p_i)]$	$s_i = 0.5 \times [-q_k(o_i + p_i) - r_k(o_i - p_i)]$
$u_i = 0.5 \times [r_{9-k}(o_i + p_i) + q_{9-k}(o_i - p_i)]$	$u_i = 0.5 \times [-r_{9-k}(o_i + p_i) + q_{9-k}(o_i - p_i)]$
method=7	method=15
$s_i = 0.5 \times [-q_{9-k}(o_i + p_i) + r_k(o_i - p_i)]$	$s_i = 0.5 \times [-q_{9-k}(o_i + p_i) - r_k(o_i - p_i)]$
$u_i = 0.5 \times [r_{9-k}(o_i + p_i) + q_k(o_i - p_i)]$	$u_i = 0.5 \times [-r_{9-k}(o_i + p_i) + q_k(o_i - p_i)]$

In the Length-100 Golay Complementary Sequence Pair Combining Rule,  $o_i$  and  $p_i$  represent elements constituting a length-10 Golay complementary sequence pair [O,P],  $q_k$ , and  $r_k$  represent elements constituting a length-10 Golay complementary sequence pair [Q,R], and  $s_i$  and  $u_i$  represent elements constituting a length-100 Golay complementary sequence pair [S,U]. Here,  $i$ ,  $l$ , and  $k$  satisfy a condition of Equation (5) below.

$$0 \leq i \leq 99-1, \quad l \equiv i \bmod 10, \quad k = \left\lfloor \frac{i}{10} \right\rfloor \quad \dots \dots \dots (5)$$

FIG. 13 is a block diagram illustrating a structure of the Golay complementary sequence conjugate pair generator 617 illustrated in FIG. 6. Referring to FIG. 13, the Golay complementary sequence conjugate pair generator 617, as described in conjunction with FIG. 6, is provided with a parameter 'seed' for selecting a conjugate pair of a primitive Golay complementary sequence pair from the controller, and generates a Golay complementary sequence conjugate pair according to the provided parameter 'seed'. A procedure for generating an actual Golay complementary sequence conjugate pair according to the parameter 'seed' will be described below.

10

The parameter 'seed' is applied to a binary converter 1311, and the binary converter 1311 converts the parameter 'seed' into a binary number. Here, because there are 64 Golay complementary sequence conjugate pairs, the parameter 'seed' has an integer of 0 to 64. Thus, the binary converter 1311 converts the parameter 'seed' into a 6-digit binary number, and each of the converted 6 binary digits will be represented by bseed[n]. That is, bseed[0] represents a value of a digit corresponding to  $2^0$  in the 6-digit binary number, bseed[1] represents a value of a digit corresponding to  $2^1$  in the 6-digit binary number, bseed[2] represents a value of a digit corresponding to  $2^2$  in the 6-digit binary number, bseed[3] represents a value of a digit corresponding to  $2^3$  in the 6-digit binary number, bseed[4] represents a value of a digit corresponding to  $2^4$  in the 6-digit binary number, and bseed[5] represents a value of a digit corresponding to  $2^5$  in the 6-digit binary number. For example, if the parameter 'seed' is 3, then bseed[5]=0, bseed[4]=0, bseed[3]=0, bseed[2]=0, bseed[1]=1, and bseed[0]=1.

In this manner, the binary converter 1311 binary-converts the parameter 'seed' and outputs bseed[5], bseed[4], bseed[3], bseed[2], bseed[1], and bseed[0]. The bseed[5], bseed[4], bseed[3], bseed[2], bseed[1], and bseed[0] are applied to a Golay complementary sequence pair converter 1313, a first sequence's order

converter 1315, a second sequence's order converter 1317, a first sequence's sign converter 1319, a second sequence's sign converter 1321, and a Golay complementary sequence pair's odd sign converter 1323, respectively.

5           A length-N primitive Golay complementary sequence pair  $[T_0, T_0^C]$  is applied to the Golay complementary sequence pair converter 1313. If bseed[5] output from the binary converter 1311 is 1, the Golay complementary sequence pair converter 1313 converts order of the length-N primitive Golay complementary sequence pair  $[T_0, T_0^C]$  into  $[T_0^C, T_0]$ , and outputs  $[T_1, T_1^C]$ . Here,  
10 the  $[T_1, T_1^C]$  represents a Golay complementary sequence output from the Golay complementary sequence pair converter 1313. In contrast, if bseed[5] output from the binary converter 1311 is 0, the Golay complementary sequence pair converter 1313 outputs  $[T_1, T_1^C]$  as it is without converting order of the length-N primitive Golay complementary sequence pair  $[T_0, T_0^C]$ .

15

The  $[T_1, T_1^C]$  output from the Golay complementary sequence pair converter 1313 is applied to the first sequence's order converter 1315. If bseed[4] output from the binary converter 1311 is 1, the first sequence's order converter 1315 converts order of a first sequence  $T_1$  of the  $[T_1, T_1^C]$  to generate it as  $T_2$ , and  
20 generates  $T_1$  as  $T_2^C$  without order conversion. In contrast, if bseed[4] output from the binary converter 1311 is 0, the first sequence's order converter 1315 generates  $[T_1, T_1^C]$  as  $[T_2, T_2^C]$  without order conversion.

The  $[T_2, T_2^C]$  output from the first sequence's order converter 1315 is  
25 applied to the second sequence's order converter 1317. If bseed[3] output from the binary converter 1311 is 1, the second sequence's order converter 1317 converts order of a second sequence  $T_2^C$  of the  $[T_2, T_2^C]$  to generate it as  $T_3^C$ , and generates  $T_2$  as  $T_3$  without order conversion. In contrast, if bseed[3] output from the binary converter 1311 is 0, the second sequence's order converter 1317  
30 generates  $[T_2, T_2^C]$  as  $[T_3, T_3^C]$  without order conversion.



The  $[T_3, T_3^C]$  output from the second sequence's order converter 1317 is applied to the first sequence's sign converter 1319. If bseed[2] output from the binary converter 1311 is 1, the first sequence's sign converter 1319 converts a  
 5 sign of a first sequence  $T_3$  of the  $[T_3, T_3^C]$  to generate it as  $T_4$ , and generates  $T_3$  as  $T_4$  without sign conversion. In contrast, if bseed[2] output from the binary converter 1311 is 0, the first sequence's sign converter 1319 generates  $[T_3, T_3^C]$  as  $[T_4, T_4^C]$  without sign conversion.

10 The  $[T_4, T_4^C]$  output from the first sequence's sign converter 1319 is applied to the second sequence's sign converter 1321. If bseed[1] output from the binary converter 1311 is 1, the second sequence's sign converter 1321 converts a sign of a second sequence  $T_4^C$  of the  $[T_4, T_4^C]$  to generate it as  $T_5^C$ , and generates  
 15  $T_4$  as  $T_5$  without sign conversion. In contrast, if bseed[1] output from the binary converter 1311 is 0, the second sequence's sign converter 1321 generates  $[T_4, T_4^C]$  as  $[T_5, T_5^C]$  without sign conversion.

The  $[T_5, T_5^C]$  output from the second sequence's sign converter 1321 is applied to the Golay complementary sequence pair's odd sign converter 1323. If  
 20 bseed[0] output from the binary converter 1311 is 1, the Golay complementary sequence pair's odd sign converter 1323 converts a sign of odd constituent elements of the two sequences  $T_5$  and  $T_5^C$  of the  $[T_5, T_5^C]$  to generate  $T_6$  and  $T_6^C$ . In contrast, if bseed[0] output from the binary converter 1311 is 0, the Golay complementary sequence pair's odd sign converter 1323 generates  $[T_5, T_5^C]$  as  
 25  $[T_6, T_6^C]$  without sign conversion. As a result, the  $[T_6, T_6^C]$  output from the Golay complementary sequence pair's odd sign converter 1323 becomes an output of the Golay complementary sequence conjugate pair generator 617.

FIG. 14 is a block diagram illustrating a mapping relation between  
 30 subcarriers and a preamble sequence during IFFT processing in an OFDM

communication system according another embodiment of the present invention. It will be assumed in FIG. 14 that the total number of subcarriers of the OFDM communication system is  $A$  and unique numbers of subcarriers actually in use among the  $A$  subcarriers are  $[-B, -B+1, \dots, -1, 1, \dots, B-1, B]$ . In FIG. 14, numerals at  
5 an IFFT processor's input terminal represent unique numbers of subcarriers in the OFDM communication system. As described above, null data is inserted into a  $0^{\text{th}}$  subcarrier because the  $0^{\text{th}}$  subcarrier, after performing IFFT, represents a reference point of a preamble sequence in a time domain, i.e., represents a DC component in a time domain. In addition, null data is also inserted into  $-(A/2)^{\text{th}}$  to  
10  $-(B+1)^{\text{th}}$  subcarriers and  $(B+1)^{\text{th}}$  to  $(A/2-1)^{\text{th}}$  subcarriers among the  $2B$  subcarriers actually in use, excluding the  $0^{\text{th}}$  subcarrier. The reason for inserting null data into the  $-(A/2)^{\text{th}}$  to  $-(B+1)^{\text{th}}$  subcarriers and the  $(B+1)^{\text{th}}$  to  $(A/2-1)^{\text{th}}$  subcarriers is because the  $-(A/2)^{\text{th}}$  to  $-(B+1)^{\text{th}}$  subcarriers and the  $(B+1)^{\text{th}}$  to  $(A/2-1)^{\text{th}}$  subcarriers correspond to a guard interval. Therefore, if the frequency-domain  
15 preamble sequence  $Sg(-B:B)$  or  $Pg(-B:B)$  is applied to the IFFT processor, the IFFT processor performs IFFT after mapping the received frequency-domain preamble sequence  $Sg(-B:B)$  or  $Pg(-B:B)$  to corresponding subcarriers, and outputs a time-domain preamble sequence. Here, the  $Sg(-B:B)$  is applied to the IFFT processor for a leading preamble sequence period in a long preamble period,  
20 while the  $Pg(-B:B)$  is applied to the IFFT processor for a short preamble sequence period.

FIG. 15 is a block diagram illustrating a mapping relation between subcarriers and a preamble sequence during IFFT processing in an OFDM  
25 communication system having 256 subcarriers. It will be assumed in FIG. 15 that there exist 256 subcarriers of  $-128^{\text{th}}$  to  $127^{\text{th}}$  subcarriers, and the number of subcarriers actually in use is 200, including  $-100^{\text{th}}$ ,  $\dots, -1^{\text{st}}, 1^{\text{st}}, \dots, 100^{\text{th}}$  subcarriers. As described in conjunction with FIG. 14, because a  $0^{\text{th}}$  subcarrier functions as a DC component and  $-128^{\text{th}}$  to  $-101^{\text{st}}$  subcarriers and  $101^{\text{st}}$  to  $127^{\text{th}}$  subcarriers

function as a guard interval, null data is inserted therein. Therefore, a frequency-domain preamble sequence  $Sg(-100:100)$  or  $Pg(-100:100)$  is inserted into an input terminal of an IFFT processor, and the IFFT processor performs IFFT on the received  $Sg(-100:100)$  or  $Pg(-100:100)$  and outputs a time-domain preamble sequence. Here, the  $Sg(-100:100)$  is applied to the input terminal of the IFFT processor for a leading preamble sequence period in a long preamble period, while the  $Pg(-100:100)$  is applied to the input terminal of the IFFT processor for a short preamble sequence period.

10           The  $Sg(-100:100)$  or  $Pg(-100:100)$  is generated by the preamble sequence generator 500 as described in conjunction with FIG. 5, and the present invention will be described on the assumption that the preamble sequence generator 500 generates  $Pg(-100:100)$ . All preamble sequences generated by the preamble sequence generator 500 have a PAPR less than 3[dB], and the lowest  
15           PAPR is 2.7448[dB] among PAPRs of all Golay complementary sequences that can be obtained by a combination of all parameters  $M$ ,  $N$ ,  $pNum0$ ,  $pNum1$ ,  $seed0$ ,  $seed1$ ,  $seed2$ , 'method', and 'select' used in the  $M \times N$  Golay complementary sequence generator of FIG. 6. The parameters  $M$ ,  $N$ ,  $pNum0$ ,  $pNum1$ ,  $seed0$ ,  $seed1$ ,  $seed2$ , 'method', and 'select' for generating a Golay complementary  
20           sequence for the  $PAPR=2.7448[dB]$  can have different values, and Table 1 below shows  $seed0$  and  $seed1$  on the assumption that  $pNum0 = pNum1 = method = select = seed2 = 0$ .

Table 1

seed0	seed1	seed0	seed1	seed0	seed1	seed0	seed1
8	49	16	41	40	43	48	51
8	55	16	47	40	45	48	53
9	49	17	41	41	43	49	51
9	55	17	47	41	45	49	53
10	17	18	9	42	11	50	19
10	23	18	15	42	13	50	21
11	17	19	9	43	11	51	19
11	23	19	15	43	13	51	21
12	17	20	9	44	11	52	19
12	23	20	15	44	13	52	21
13	17	21	9	45	11	53	19
13	23	21	15	45	13	53	21
14	49	22	41	46	43	54	51
14	55	22	47	46	45	54	53
15	49	23	41	47	43	55	51
15	55	23	47	47	45	55	53

In Table 1, if  $pNum0 = pNum1 = method = select = seed2 = 0$ ,  $seed0 = 8$ , and  $seed1 = 49$ , then a preamble sequence  $Pg(-100:100)$  is given by

5

$$Pg(-100:100) = \{0,-1, 0,-1, 0,+1, 0,-1, 0,+1, 0,-1, 0,+1, 0,+1, 0,-1, 0,-1, \\ 0,+1, 0,+1, 0,-1, 0,+1, 0,-1, 0,+1, 0,-1, 0,-1, 0,+1, 0,+1, \\ 0,+1, 0,+1, 0,-1, 0,+1, 0,-1, 0,+1, 0,-1, 0,-1, 0,+1, 0,+1, \\ 0,-1, 0,-1, 0,+1, 0,-1, 0,+1, 0,-1, 0,+1, 0,+1, 0,-1, 0,-1, \\ 0,-1, 0,-1, 0,+1, 0,+1, 0,+1, 0,+1, 0,+1, 0,-1, 0,+1, 0,+1, \\ 0,-1, \\ 0,-1, 0,+1, 0,-1, 0,+1, 0,-1, 0,+1, 0,+1, 0,-1, 0,-1, 0,-1, \\ 0,-1, 0,+1, 0,+1, 0,+1, 0,+1, 0,+1, 0,-1, 0,+1, 0,+1, 0,-1, \\ 0,-1, 0,+1, 0,+1, 0,+1, 0,+1, 0,+1, 0,-1, 0,+1, 0,+1, 0,-1, \\ 0,-1, 0,+1, 0,+1, 0,+1, 0,+1, 0,+1, 0,-1, 0,+1, 0,+1, 0,+1, \\ 0,+1, 0,-1, 0,-1, 0,-1, 0,-1, 0,-1, 0,-1, 0,+1, 0,-1, 0,-1, 0\} \\ *sqrt(2)*sqrt(2)\pm 1$$

Describing the Pg(-100:100), it can be noted that data of +1 or -1 is inserted into odd constituent elements while null data, or 0, is inserted into even 10 constituent elements.

FIG. 16 is a flowchart illustrating a preamble sequence mapping procedure according to another embodiment of the present invention. Referring to FIG. 16, a transmitter determines in step 1611 whether a current signal

transmission period is a preamble sequence transmission period. If the current signal transmission period is not a preamble sequence transmission period but a data transmission period, the transmitter proceeds to step 1613. In step 1613, the transmitter maps transmission data to corresponding subcarriers on an IFFT processor's input terminal, and then ends the procedure.

However, if it is determined in step 1611 that the current signal transmission period is a preamble sequence transmission period, the transmitter proceeds to step 1615. In step 1615, the transmitter determines whether the preamble sequence transmission period is a period for which a leading preamble sequence of a long preamble sequence is transmitted. Here, in the preamble sequence transmission period, the leading preamble sequence of a long preamble sequence means a sequence  $Sg(-100:100)$ . If it is determined that the preamble sequence transmission period is a period for which a leading preamble sequence of a long preamble sequence is transmitted, the transmitter proceeds to step 1617.

In step 1617, the transmitter generates a leading preamble sequence  $Sg(-B:B)$  of the long preamble sequence, maps the generated preamble sequence  $Sg(-B:B)$  to corresponding subcarriers on the IFFT processor's input terminal, and then ends the procedure. Here, " $-B:B$ " represents unique numbers of subcarriers where data is actually used in the OFDM communication system. However, if it is determined in step 1615 that the preamble sequence transmission period is not a period for which a leading preamble sequence  $Sg(-B:B)$  of a long preamble sequence is transmitted, i.e., if the preamble sequence transmission period is a period for which a short preamble sequence  $Pg(-B:B)$  is transmitted, then the transmitter proceeds to step 1619. In step 1619, the transmitter generates the short preamble sequence  $Pg(-B:B)$ , maps the generated short preamble sequence  $Pg(-B:B)$  to corresponding subcarriers on the IFFT processor's input terminal, and then ends the procedure.

30

As can be understood from the foregoing description, the present invention generates a preamble sequence having a minimum PAPR below 3[dB] at the maximum, contributing to improvement in overall performance of an OFDM communication system. In addition, the present invention generates a  
5 preamble sequence using a Golay complementary sequence, making it possible to generate a preamble sequence having a minimum PAPR with the minimized number of operations within the shortest time.

While the present invention has been shown and described with reference  
10 to certain preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.